Roberson and Associates, LLC

Technology and Management Consultants

CHICAGO, IL R.F. MEASUREMENT TEST PLAN

AWS-3 CLUTTER MODEL VALIDATION

20 October 2015, v1.3-FCC

Baseline Plan

Background

This work area is part of the DISA Transition Plan Spectrum Sharing Test & Demonstration Program.

The stated goal is to:

> Conduct RF Measurements in Chicago to Validate DoD AWS-3 band Propagation Loss Clutter Models

The process associated with this goal is:

1. Test Plan (this document)
    a. Actionable plan that meets milestones and goals
    b. Coordination plan with other relevant DoD/contractor teams
2. Phase 1 Measurement Campaign
    a. RF Measurement data that can be used to validate clutter models
    b. Technical memo/report on test system, measurement process, data formats and processing steps, among other areas as deemed essential for data transfer and use
3. Analysis and Conclusions and Next Steps
    a. Measured clutter propagation loss in common parameters and units with respect to the models
    b. Identification of open issues, gaps, etc. and identification of resolution steps
    c. Determination if Phase 2 measurements are necessary

The primary area of interest for measurement is the Chicago Loop. Secondary areas of interest include light urban environments to the north and west and suburban environments to the west. The working assumption for this plan is that a transmissions originating on the IIT Tower roof and operating in the AWS-3 Up Link band (1755 – 1780 MHz) will be received in the Chicago Loop by a mobile receive node. The following figure shows a Google Earth rendering of the environment looking north from the IIT Tower (shown by the orange pin symbol).

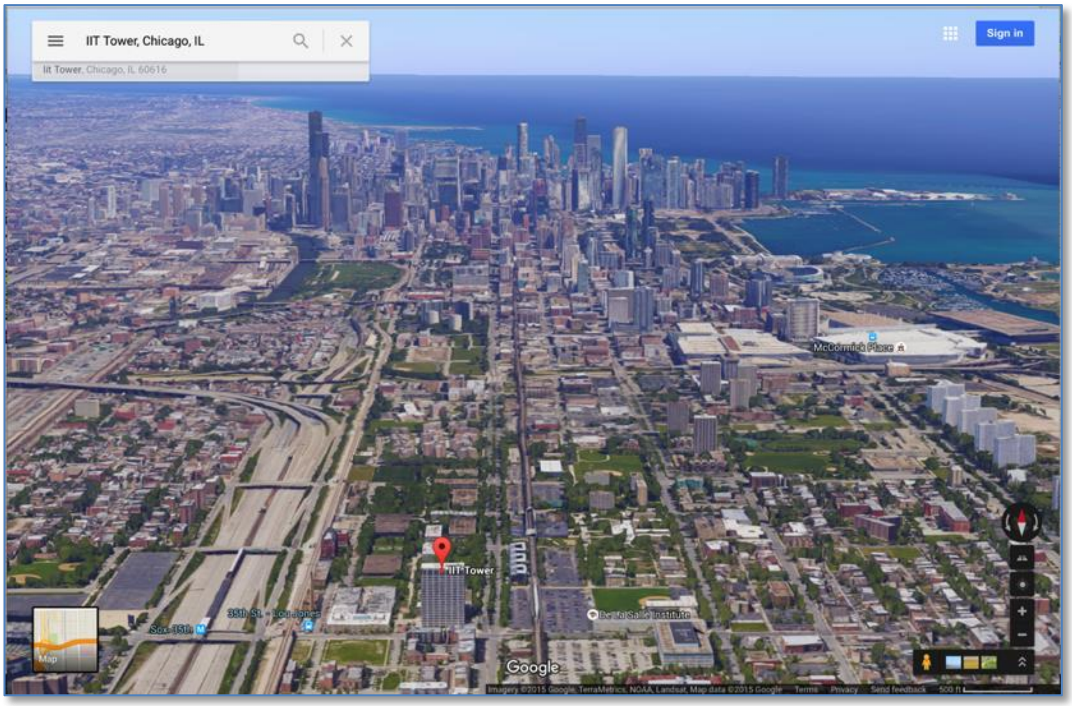

Figure 1. Primary Chicago, IL R.F. Measurement Test Environment

Note that the IIT Tower (10 West 35th Street, Chicago, IL) is significantly higher than most other buildings to the north until the Loop area is encountered.

Schedule

The following draft schedule is in place:

Milestone	Date	Status
Test Plan draft complete	9/30/2015	Completed
Test Plan draft reviewed and approved	11/1/2015	Not Started
Test System assembled and deployed	11/15/2015	Not Started
Test System tested	11/22/2015	Not Started
Phase 1 Field Tests complete	12/15/2015	Not Started
Phase 1 Field Test Technical Memo released	12/31/2015	Not Started
Phase 1 data reviewed	1/22/2016	Not Started
Decision on need for Phase 2 Field Tests	1/31/2016	Not Started
Phase 2 Field Tests complete (in needed)	3/7/2016	Not Started

Table 1. Chicago, IL R.F. Measurement Test Plan Schedule

System Gain Analysis

The following figure shows the system gain analysis, which assumes a 120-watt transmitter that feeds a 17.7 dBi gain directional antenna installed on the edge of the IIT Tower roof.

A narrowband receiver is required to attain the necessary system gain, resulting in the assumption of a 100 kHz noise equivalent bandwidth (NEB) receiver node. A LNA will be placed prior the receiver front end in order to minimize the Noise Figure (NF). An Omni antenna installed 7 feet above the ground is assumed.

We assume a fourth-power propagation loss between the IIT Tower and the edge of the Chicago Loop (4.2 km propagation distance). The (differential) Urban ECC-33 model is used to model propagation loss into the Loop (1.2 km distance into the Loop assumed).

T3748 Task 9.4: System Gain Analysis for AWS-3 Clutter Model Validation R.F. Measurements

Propagation Model Parameters		
Transmitter Antenna Height		
Hb (IIT Tower)	70.0	m
Receiver Antenna Height		
Hr (Sensor)	2.2	m
Link Parameters		
f (Center)	1760.0	MHz
dL (Sensor in Loop)	1.20	km
dO (IIT Tower to Loop)	4.20	km
IIT Tower to Loop Prop Model Type		
Model Name	4thPower	
IIT Tower to Loop Loss	at dO =	4.2
4thPower	122.29	dB
Urban ECC-33 Loss	at dL =	1.2
	40.73	dB
Total Path Loss	163.0	dB

Link Budget Parameters			
IIT Tower Transmit System			
Ptx	50.8	dBm	TX Power
Gtx	17.7	dB	Antenna Gain
Ltx	5.0	dB	Losses
Sensor Receiver System			
Prx	-101.02	dBm	Radar RX Power
Grx	1.5	dB	Antenna Gain
Lrx	2.0	dB	Losses
Other Losses			
Lm	1.0	dB	Miscellaneous
S/N	**20.98**	**dB**	**RX Signal-to-Noise Ratio**

Measurement BW	0.10	MHz
Noise Figure	2.00	dB
Noise Power (N)	-122.00	dBm

Figure 2. System Gain Analysis

The estimated median propagation loss of 163 dB is higher than that predicted by Hata or COST 231 large city models using the same parameters (and 5.4 km total propagation distance). Thus, an argument could be made that this is a conservative result. However, the application of general propagation models to a specific case can lead to large deviations from the predicted value.

Note that this analysis predicts a median Signal to Noise Ratio (SNR) of almost 21 dB. Thus, the system could experience 10 dB of additional loss (e.g., lognormal fading) while maintaining a reasonable SNR. Ten dB represents approximately one-sigma of lognormal fading. Thus, in very rough terms we are predicting 67% coverage at a 1.2 km distance into the Loop. Actual system coverage will depend on the actual propagation losses experienced as a function of location.

This result can be characterized as a generally workable system. Data collection will need to be limited to from the south edge of the Loop to approximately 1.5 km or less northern penetration.

Measurement System

Transmitter

The equipment employed on the transmitting side of the system is:

- A signal generator, configured to output a CW signal at 1760 MHz
- Optionally, a GPS receiver for frequency reference
- A power amplifier of nominal 120 watt output power
- A directional antenna with approximately 17.7 dBi gain.

Detailed antenna pattern information provided by the manufacturer will be used to correct for vertical and horizontal gain variation based on the locations of the mobile receiver. If measurement of the actual antenna pattern is a requirement, then there will be additional development delays and costs (i.e., schedule time on a third party measurement system and the associated fees).

The signal generator is used to generate a continuous-wave (CW) signal that is input to the power amplifier and sent to the transmit antenna. A schematic of this is shown in Figure 3.

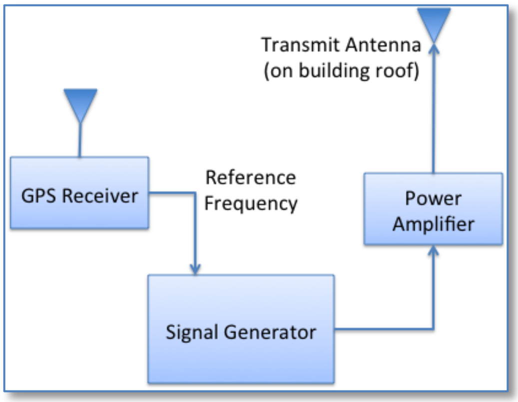

Figure 3. Measurement System Transmitter Diagram

The following table contains a notional equipment list. Depending on availability, equivalent equipment may be substituted for those described in this list.

Item	Company	Model	Comments
Transmit antenna	COMMSCOPE	HBX-6516DS-VTM	~65 degree sector antenna, ~17 dBi gain
Power amplifier	Amplifier Research	120S1G4	120 W output
Signal generator	Aeroflex	2024	
Coax cable			600 Series Low-Loss Cable
GPS receiver	TBD	TBD	

Table 2. Transmitter Notional Equipment List

Receiver

The equipment used on the receiving side of the measurement system is:

- An omnidirectional antenna that can operate in the 1755 – 1780 MHz band

  Given that urban areas in general (and the Chicago Loop in particular) result in highly scattered R.F. environments, there may be little utility associated with accurately measuring the receive antenna pattern. Even were such measurements possible within reasonable cost and time constraints, uncertainty regarding the directions from which scattered R.F. signals arrive would significantly reduce the value of this information.

- A band-pass filter to limit the noise and out of band energy coming into the low noise amplifier (LNA)

- An LNA to enhance the overall noise figure of the measurement system

- A spectrum analyzer to measure the received signal power.
- A GPS receiver to capture the location at which the data is measured.

A schematic of the receiving side of the system is shown in Figure 4.

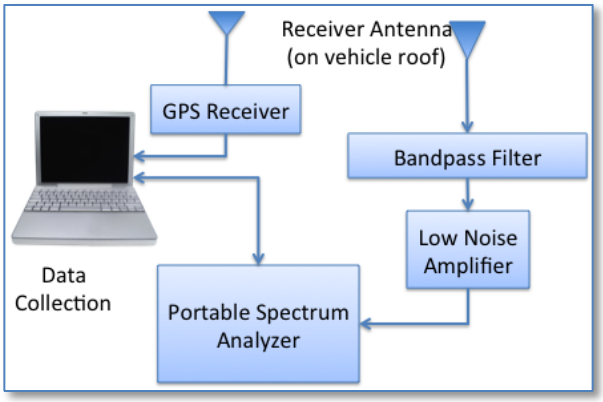

Figure 4. Measurement System Receiver Diagram

The following table contains a notional equipment list. Depending on availability, equivalent equipment may be substituted for those described in this list.

Item	Company	Model	Comments
Antenna			Omnidirectional, gain TBD
Low Noise Amp	MiniCircuits	ZX60-P33ULN+	
Band-pass Filter	Anatech Electronics	AE1750B11120	Pass-band: 1732.5~1767.5 MHz
Real-Time Spectrum Analyzer	Berkeley Nucleonics	BNC RTSA7500	
GPS receiver	TBD	TBD	
Laptop PC			Generic laptop

Table 3. Receiver Notional Equipment List

Transmitter Deployment

Roberson and Associates will deploy a north-facing antenna on the edge of the IIT Tower roof for Phase 1. If practicable, the antenna will be moved to a second north-facing location and a drive test route identical to that of the first location will be measured.

In a potential Phase 2 we can move the antenna to the west side of the roof, enabling light-urban and possibly suburban measurements.

Primary Data Collection Area: Chicago Loop

Prior to the measurement campaign it will be necessary to do a pre-planning site survey and a spectrum survey along the drive route in the 1755 to 1780 MHz (AWS-3) band. The site survey will entail mapping out drive routes in the Chicago Loop. We are investigating the feasibility of using the IIT Spectrum Observatory data to determine a transmitting frequency in accordance with our (special temporary authority) STA to transmit in or near the 1755-1780 MHz frequency band. This site survey/spectrum survey will typically take from 2-3 days to complete. This pre-planning information will be discussed with DISA as completed.

We have chosen the Illinois Institute of Technology (IIT) Tower building as the transmitter site. This building is located about 3 miles south of the Chicago Loop; the roof of the building is 273 feet above ground level and, as seen in Figure 5, there is an unobstructed view of the Loop. Other reasons for choosing this site is the presence of Roberson and Associates offices in the building and the team's familiarity with the facility for the required test equipment and antenna mounting.

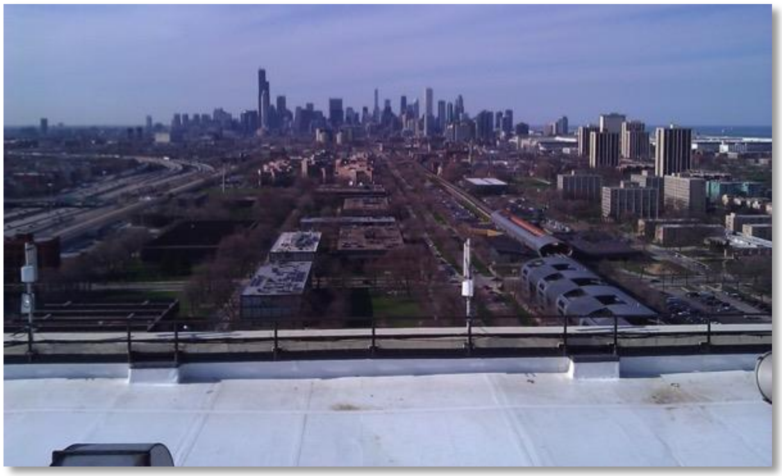

Figure 5. North View (towards Chicago Loop) from the IIT Tower Roof

An important planning step is to estimate the received signal level in the region of interest. Figure 6 shows an estimated coverage map generated using a tool called SPLAT (RF Signal Propagation, Loss and Terrain tool) which is an implementation of the well-known Longley-Rice Irregular Terrain Model (ITM) supplemented with additional data management and plotting code (http://www.qsl.net/kd2bd/splat.html).

Terrain data is based on the Space Shuttle Radar Topography Mission (SRTM). This data is available freely online from the United States Geological Survey (USGS) website with 3 arc-second and 1 arc-second resolution. Links may be found on the SPLAT website given above. This particular map was generated using 1720 W ERP.

As a point of reference in the map that follows the Willis Tower (formerly known as the Sears Tower) is near the middle of this region. The darker blue and gray shaded region is the RF shadow of this particular building. Note that a substantial portion of the region shown is predicted to have a received signal level of -90 dBm or better; this should be sufficient to take useful clutter measurements.

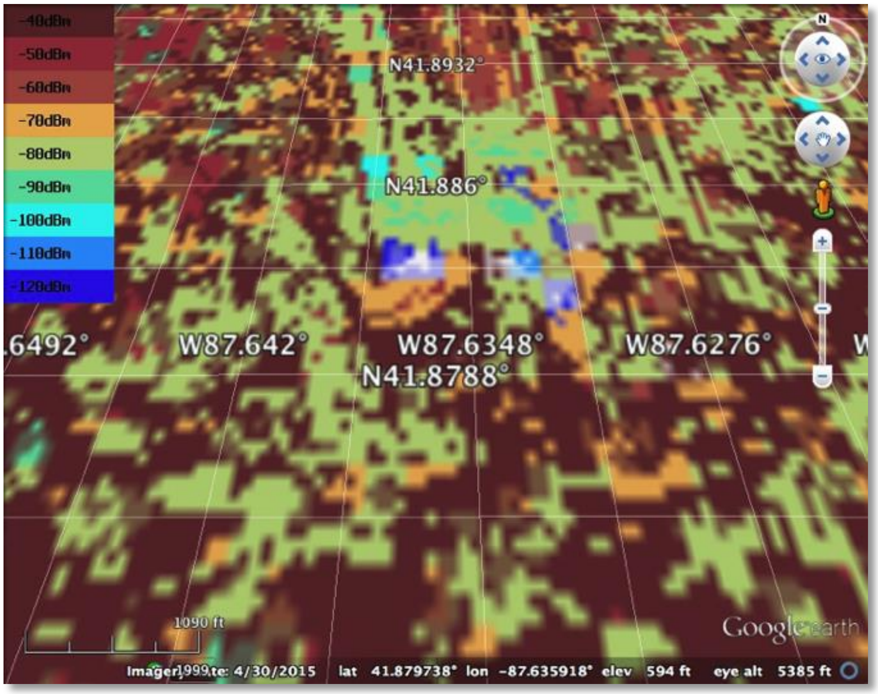

Figure 6. Estimated (SPLAT) Chicago Loop Coverage

Secondary Data Collection Areas

Chicago Light Urban

Light Urban measurements can be obtained via two means:

1. North facing transmit antenna with measurements between the IIT Tower and the Chicago Loop
2. West facing transmit antenna with measurements in light urban areas west of the IIT Tower.

Note that there may be security issues associated with drive tests in some urban neighborhoods to the west of the IIT Tower. Additional assessments will be necessary to determine if sufficient secure areas are available to conduct substantive RF measurements.

Chicago Suburban

The suburbs of Chicago began 6-8 miles to the west of the IIT Tower. Additional analysis has been conducted to determine if the transmit system will have sufficient range to enable substantive RF measurements in these areas. The results of this analysis indicate that suburban measurements will likely be possible.

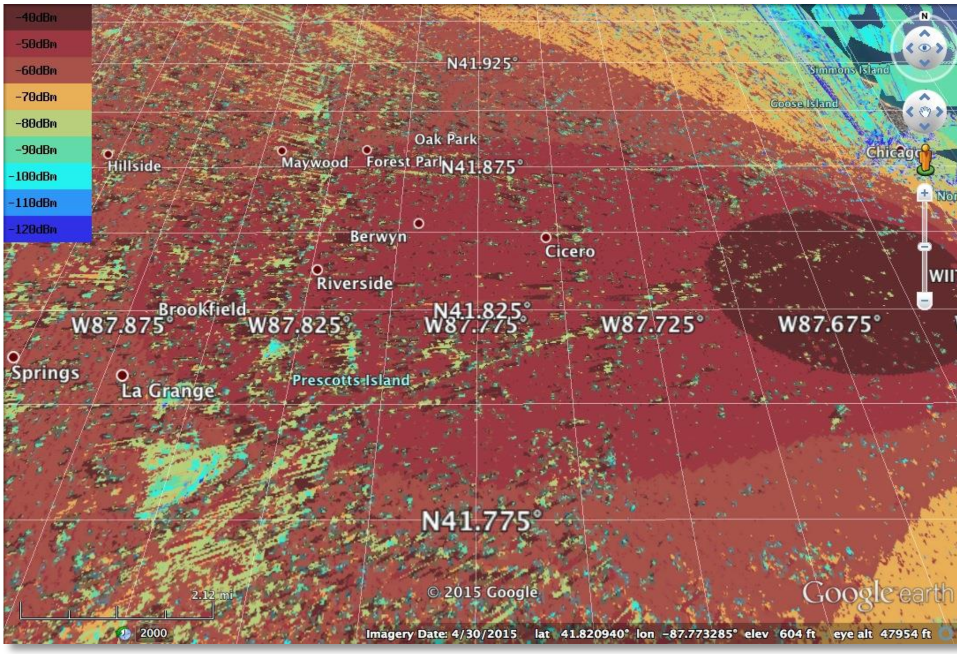

Figure 7. Estimated (SPLAT) Chicago Western Coverage (Light Urban and Suburban)

Data Processing

Data Format

The data format proposed by ITS will be followed and is shown in Figure 8.

Xmit Antenna Height (m):	10.7	
Rcv Antenna Height (m):	3	
Xmit Latitude:	39°49′34.53″N	
Xmit Longitude:	105°04′55.74″W	
Xmit Power (dBm):	46	
Tx Losses (dB):	5	
Rx Losses (dB):	5	
Receive Latitude	Receive Longitude	Median Trans. Gain(dB)
39.746502	-104.998758	-144.9417583
39.746445	-104.998685	-145.1316875
39.746387	-104.998613	-145.5074674
39.746325	-104.998543	-145.8178417
39.746262	-104.99847	-145.5775959
39.746198	-104.998388	-144.1137862
39.746133	-104.998305	-143.7575198
39.746068	-104.998217	-145.1365985
39.746003	-104.998128	-145.3075627
39.745937	-104.998045	-145.3851125
39.745868	-104.997968	-147.3313977
39.7458	-104.997893	-146.3666192
39.745732	-104.99782	-145.7088661
39.745608	-104.997667	-146.1348499
39.745547	-104.997593	-144.8948477
39.745485	-104.997522	-143.7515514
39.745425	-104.99745	-145.4407005
39.74537	-104.997372	-144.7619653
39.745315	-104.997302	-145.2137271
39.745257	-104.997238	-145.6750365

Figure 8. ITS Proposed Data Format

Data Processing

The following process is described in the ITS test plan and will be followed as closely as possible with the noted limitations.

> The average power for the spectrum analyzer traces is computed and antenna gain corrections[1] are obtained from the transmitting elevation and antenna height, the receiving antenna elevation and height, and the distance between the transmitting antenna and the receiving antenna.

ITS used both a spectrum analyzer (SA) and a vector signal analyzer (VSA). It appears that they did that because the spectrum analyzer had GPS capability and the VSA did not. Thus they aligned the data from the SA and VSA after the fact and were able to get I and Q data from the VSA, compute the received power and attach the data to the coordinates captured by the SA. We intend to use a separate GPS receiver and a spectrum analyzer.

ITS defined the following:

- Clutter loss = ITM model – measured data
- Diffraction loss = free-space – ITM model
- Clutter gain = measured – free-space

Using these definitions, they created plots of probability and cumulative distributions for clutter loss, diffraction loss, elevation angle vs. clutter loss and distance vs. clutter loss.

The implementation of the ITM model that we have used is built into the SPLAT tool described earlier. SPLAT uses measured terrain data, which includes building heights. One approach would be to share our raw data with ITS who could do the post-processing needed to extract the clutter loss and diffraction loss.

Risks and Uncertainties

The following list contains the currently known items.

1. Acquisition of the FCC STA (Status: Application sent to the FCC)
2. Approval to use the IIT Tower roof (Status: In progress, no access known issues, $900 per month IIT rental cost)
3. Winter weather constraints on field data collection
4. Coordination with the AWS-3 license holder (Status: TBD)
5. Personnel, equipment and vehicle availability (Status: TBD)
    a. Purchase / Rental costs
    b. Availability timeframes

[1] Given that urban areas in general (and the Chicago Loop in particular) result in highly scattered R.F. environments, there may be little utility associated with accurately measuring the receive antenna pattern. Even were such measurements possible within reasonable cost and time constraints, uncertainty regarding the directions from which scattered R.F. signals arrive would significantly reduce the value of this information.